The impact of centennial-scale solar forcing on the Holocene climate: simulations with a coupled climate model

Hans Renssen
Faculty of Earth & Life Sciences, Vrije Universiteit Amsterdam, The Netherlands (hans.renssen@geo.falw.vu.nl)
Hugues Goosse
Institut d'Astronomie et de Géophysique G. Lemaitre, Université Catholique de Louvain, Belgium
Raimund Muscheler*
NASA/Goddard Space Flight Center, Climate & Radiation Branch, Greenbelt, MD 20771, USA
*present affiliation: Dept. of Geology, GeoBiosphere Science Centre, Lund University, Sweden

vrije Universiteit amsterdam
UCL Université catholique de Louvain
NASA

Model and experimental design

To study the impact of decadal-to-centennial scale variations in total solar irradiance (TSI) on climate, we have performed 9000-yr-long transient experiments with the ECBilt-CLIO-VECODE 3D global model that describes the coupled atmosphere-sea ice-ocean-vegetation system. The model consists of 3 components:

1) ECBilt[1] a low resolution atmospheric QG model (T21, 3 layers)
2) CLIO[2] an oceanic general circulation model coupled to a comprehensive dynamic-thermodynamic sea-ice model, and
3) VECODE[3] a model that describes the dynamics of grassland and forest, and desert as a dummy vegetation type.

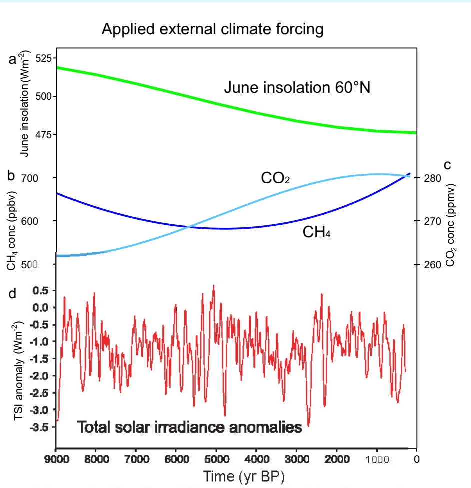


Figure 1a-d: external forcing used to drive the model: a) June insolation at 60°N, **b) atmospheric** CH_4 concentration, c) atmospheric CO_2 concentration and d) TSI anomalies (added to the solar constant).

The experiment was forced by annually changing insolation (see Fig. 1a), long-term trends in atmospheric CH_4 and CO_2 concentrations (Fig. 1b) and TSI anomalies based on delta-14C. All other boundary conditions were fixed at their 1750 AD values. Initial conditions were taken from a 500-yr equilibrium simulation with boundary conditions for 9 ka BP.

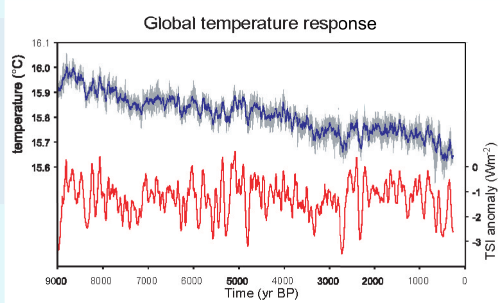


Figure 2: Simulated 5-member ensemble mean annual global surface temperature (blue) and ensemble range (grey), plotted together with prescribed TSI anomalies (red).

Global temperature response

The annual mean global temperature evolution (Fig.2) reveals a long-term cooling trend as a response to orbital forcing (Fig. 1a). The decadal-centennial scale variations superimposed on this long-term cooling trend are primarily associated with the applied solar forcing.

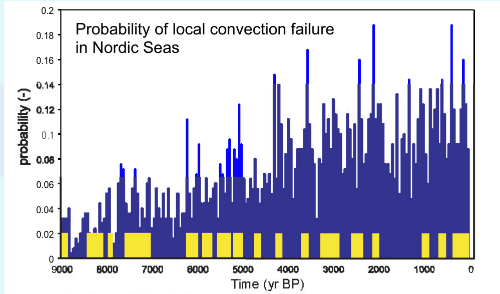


Figure 3: **Probability to have a year with deep convection** failure in the Nordic Seas (per 50-yr periods). The probability peaks during large negative TSI anomalies (yellow bars).

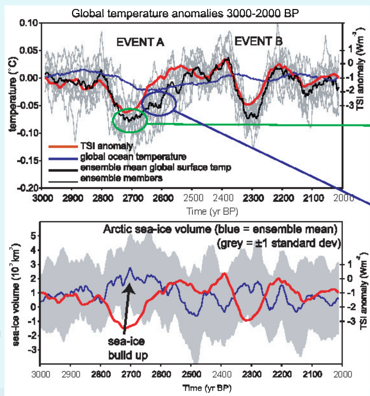
Deep convection failure in Nordic Seas

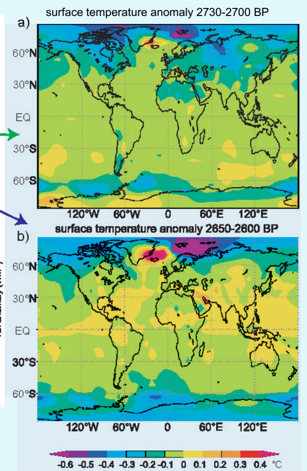
During large negative TSI anomalies, sea-ice expands in the Nordic Seas due to the solar-forced decline in temperature, leading to stratification of the water column. This increases the probability of a local deep convection failure (Fig. 3). If this occurs, the sea-ice cover expands further, enhancing the cooling, thus representing a positive feedback.

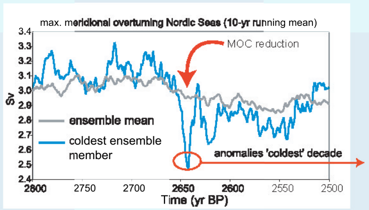
Response 3000-2000 BP

Generally, global surface temperature closely follows TSI, except during long-lasting TSI anomalies such as event A centered at 2700 BP. The cooling event lasts about 50-year longer than the TSI anomaly. This is caused by extensive sea-ice build-up, which hampers the reinitiation of deep convection South of Svalbard. The characteristic temperature anomaly pattern shows cool conditions over the Arctic, with a minimum near Svalbard and warming over Iceland.

During shorter TSI anomalies, such as event B centered at 2300 BP, sea-ice build-up is insufficient to cause this lag effect and the global temperature is in phase with TSI.

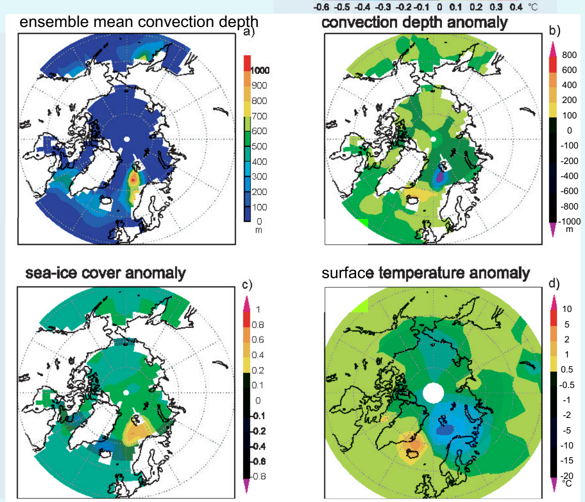






Deep convection around 2700 BP

In most cases when deep convection fails at our main site (South of Svalbard), deep convection shifts to a location near Iceland. Only in 2 out of 9 cases, the overturning circulation is actually signifcantly weakened in the Nordic Seas. When this happens, the cooling is much more severe (more than 10°C) and sea ice expands even further.



Additional information:
Renssen, H., Goosse, H., Muscheler, R. 2006.Coupled climate model simulation of Holocene cooling events: oceanic feedback amplifies solar forcing. Climate of the Past 2, 79-90.

References:
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